MODELING CLOSE-IN AIRBLAST FROM ANFO CYLINDRICAL AND BOX-SHAPED CHARGES

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ABSTRACT

Personnel of the U. S. Army Engineer Research and Development Center recently investigated close-in airblast (250 MPa to 600 MPa peak reflected pressures) through a series of experiments and numerical simulations. Cylindrical and box-shaped charges of ammonium nitrate with fuel oil (ANFO) were detonated at various heights above a heavy steel plate. The plate was instrumented with twelve PCB piezoelectric pressure sensors with a maximum range of 827 MPa (120 ksi). Eight additional HKS piezoresistive pressure gages were placed on two radials on the ground beyond the plate. This paper describes the experimental program and its results, accompanying calculations with a hydrodynamics code, and development of the engineering-level code CAB (Close-in Airblast) for calculation of the reflected pressures.

OBJECTIVE

Most experimental programs investigating airblast loads from makeshift explosive devices were limited to pressures below about 2 MPa. The objectives of our work were to extend the database much closer toward the explosive charge and to obtain reflected pressure measurements from cylindrical and box-shaped charges at fully 3-D orientations not commonly used in experimental programs. The results of the experiments will then be used for validation of results from high-fidelity and engineering-level calculations.

EXPERIMENTAL PROGRAM

The work described in this paper obtained reflected pressure measurements in the close-in region for scaled heights of burst from 0.185 m/kg$^{1/3}$ to 0.27 m/kg$^{1/3}$, where peak pressures up to about 700 MPa were predicted. Explosive charges of commercial ammonium nitrate with fuel oil (ANFO) were used in cylinders with length-to-diameter ratios of one and box shaped charges with length/width/thickness ratios 2:2:1. ANFO is highly nonideal and cannot be accurately scaled with common cube root scaling from 10s of kg to 10,000s of kg.

The explosive charges were detonated at their geometrical centers using booster charges of Composition C-4 that were about 1.3% of the ANFO mass. The average density of the ANFO was about 0.82 g/cm^3. All of the charges were enclosed in Styrofoam containers to avoid damage to pressure sensors. Figure 1 shows the configuration of a cylindrical charge positioned above the center of a steel plate with its axis parallel to the ground surface. Figure 2 shows the orientation of a box-shaped charge. Both figures also show the steel plate and four of the gage mounts beyond the plate.

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Figure 1. Charge and gage layout for a cylindrical explosive charge.

Figure 2. Charge orientation for a box-shaped explosive charge.

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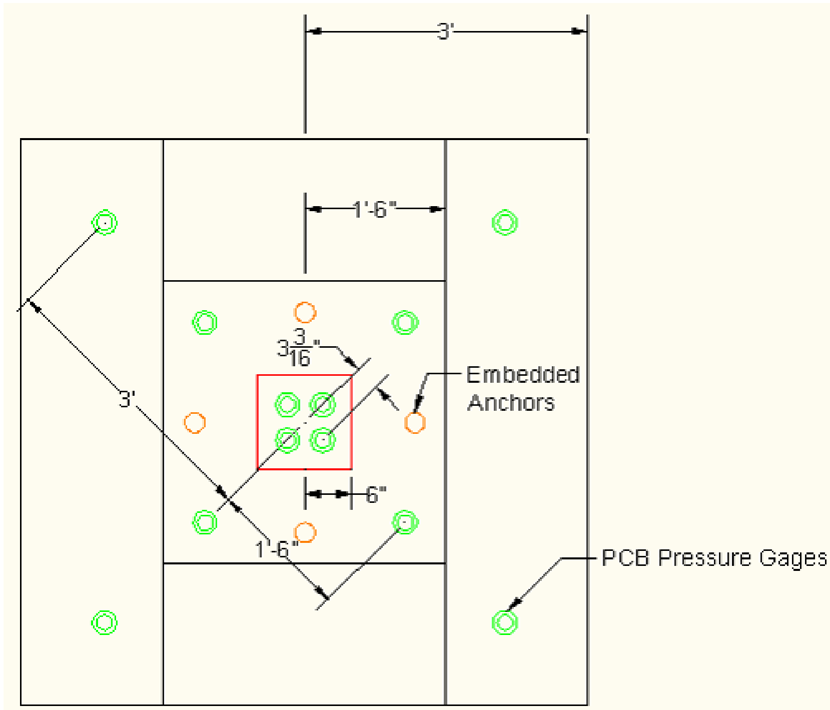

Figure 3. Locations of PCB pressure gages on the steel plate.

Twelve PCB piezoelectric pressure transducers (827-MPa range) were mounted on the 183 cm by 183 cm (6ft by 6 ft) steel plate as shown in Figure 3. These gages were at ranges 0.0762, 0.457, and 0.914 m from the center. An additional eight HKS piezoresistive transducers were positioned flush with the ground surface along two radials A and B that are, respectively, parallel to the cylinder's axis (0 deg) and perpendicular to the cylinder's axis (90 deg). The 0-deg radial is shown in Figures 1 and 2. The smallest dimension of the box-shaped charges is aligned with this radial. These HKS gages extended out to 7.62 m from the center of the steel plate.

Figures 4 – 6 show examples of measured peak pressures for the cylindrical explosions at scaled height of bursts (HOB) of about 0.28 m/kg$^{1/3}$. Figures 4 and 5 compare results for the cylinder of Test 2 with the box-shaped charge of Test 8. Along the 0-deg radial, peak pressures for the two charge shapes scatter together. Along the 90-deg radial, pressures from the cylindrical charge were consistently higher. Figure 6 compares peak pressures on the 0-deg and 90-deg radials for the box-shaped charge of Test 8. Pressures on the 90-deg radial were about a factor of two higher than on the 0-deg radial.

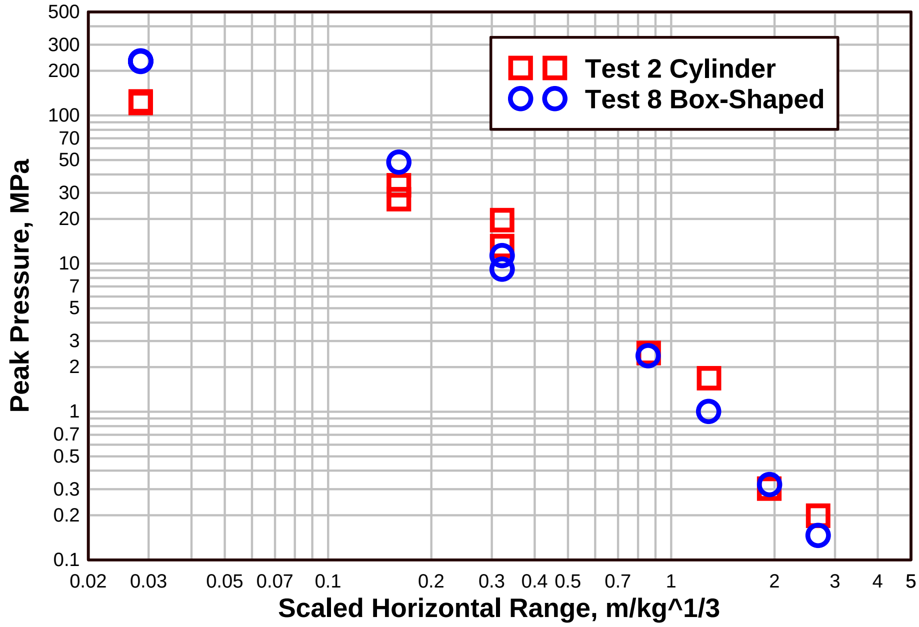

Figure 4. Peak pressures from Tests 2 and 8 on radial A, 0 deg.

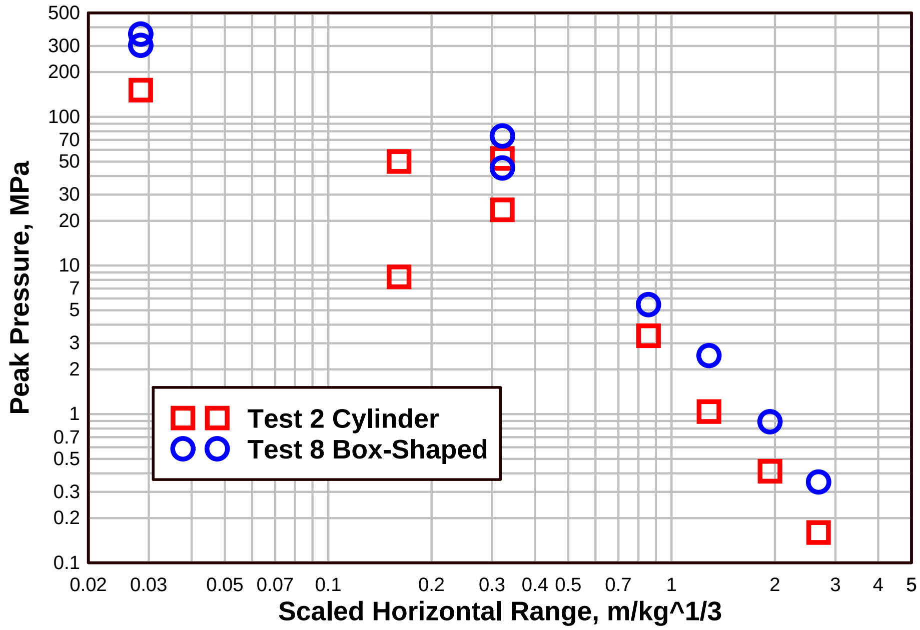

Figure 5. Peak pressures from Tests 2 and 8 on radial B, 90 deg.

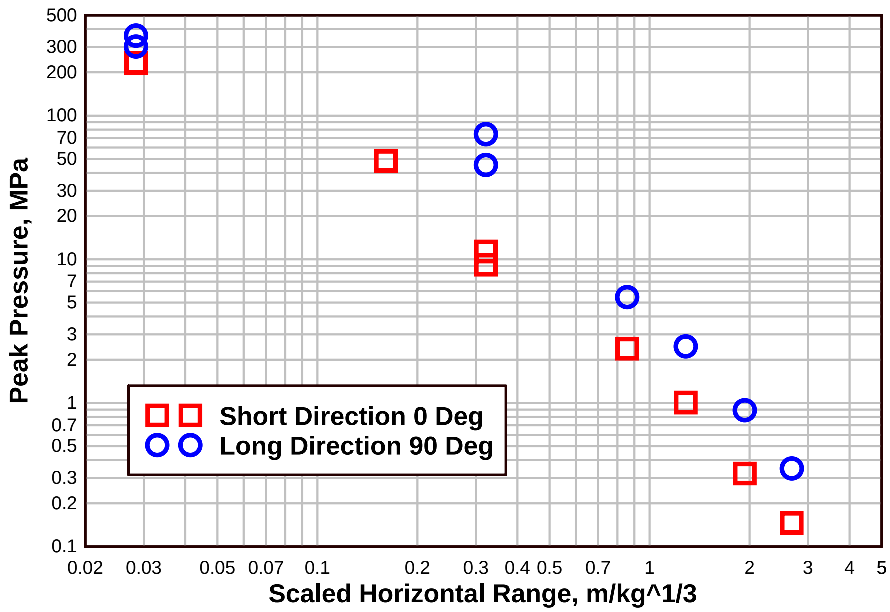

Figure 6. Peak pressures from Test 8 (box-shaped charge) on 0-deg and 90-deg radials.

CALCULATIONS

Pretest and posttest calculations were performed with the SAGE Eulerian hydrodynamics code [1]. The Jones-Wilkins-Lee (JWL) equation of the state (EOS) [2] of the reacted ANFO was computed using the Cheetah thermodynamics code [3]. Cheetah first calculates the detonation state from Chapman-Jouget (C-J) theory and then models the adiabatic expansion from the C-J state to one atmosphere. The JWL EOS is a curve fit to these thermodynamic states. It is well known that these EOSs are suitable for fully reacted materials, and in the case of nonideal explosives such as ANFO, represent an ideal detonation realized only in very large charges [4, 5]. The detonation velocity varies considerably depending on the charge size and confinement and how the explosion is initiated.

We have had good success modeling a large range of ANFO charge sizes using the Cheetah-generated EOS along with the Ignition and Growth (IG) reactive flow model [6] that determines the reaction rate as a function of the local state variables of pressure and density. For ANFO, a generalized IG version with a second growth (or completion) term is appropriate to model the late-time reaction of the explosive. We constructed and calibrated our IG model with explosive field test data from the Energetic Materials Research and Testing Center (EMRTC) [7] and other measurements such as in references [4, 5]. Other researchers [8, 9, 10] applied Arrhenius kinetics and divergent flow models to ANFO explosions, but none of these papers compared their results with field test data.

The SAGE calculations were first performed as 2-D axisymmetric using extremely fine zoning (0.25-mm minimum cell size) and dynamic adaptive mesh refinement (AMR).

At times corresponding to shock arrival at the steel plate for various HOBs, the 2-D results were overlaid into a 3-D grid. Initially, a minimum cell size of 4 mm was used until the number of AMR cells reached about 300 million. Then, the minimum cell size was increased to 8 mm and finally to 16 mm.

Figures 7 and 8 compare results from our SAGE calculations with measured peak pressures and impulses, respectively, from Tests 5 and 6 that involved cylinders at a nominal scaled height of burst (HOB) of 0.20 m/kg$^{1/3}$. The completion term of our IG model adds considerable impulse at the larger horizontal ranges but has little effect on the peak pressure or impulse at the smaller ranges. Based on these comparisons, our IG model appears to have an average detonation velocity slightly too high, and consequently, produces pressures higher than the measurements at the smallest ranges. These calculations are sensitive to the detonation model, because detonation products follow closely behind the leading air shock. In contrast, comparisons with measurements at pressures below about 2 MPa show much less sensitivity to the detonation modeling.

Figure 9 compares measured pressure waveforms with the SAGE calculation at gages 5 and 9 at the 90-deg orientation and scaled horizontal range of 0.161 m/kg$^{1/3}$. The large variations in peak pressures and impulses at this range illustrate the difficulty in measuring (and calculating) pressures in the close-in regime.

Figure 10 compares measured and calculated pressure and impulse waveforms at the 0-deg orientation and scaled horizontal range of 0.858 m/kg$^{1/3}$, where pressure on the ground is about 3 MPa. This range is near the beginning of most field test measurements. SAGE calculations are between the measurements of the two tests, but shock arrival time is slightly early.

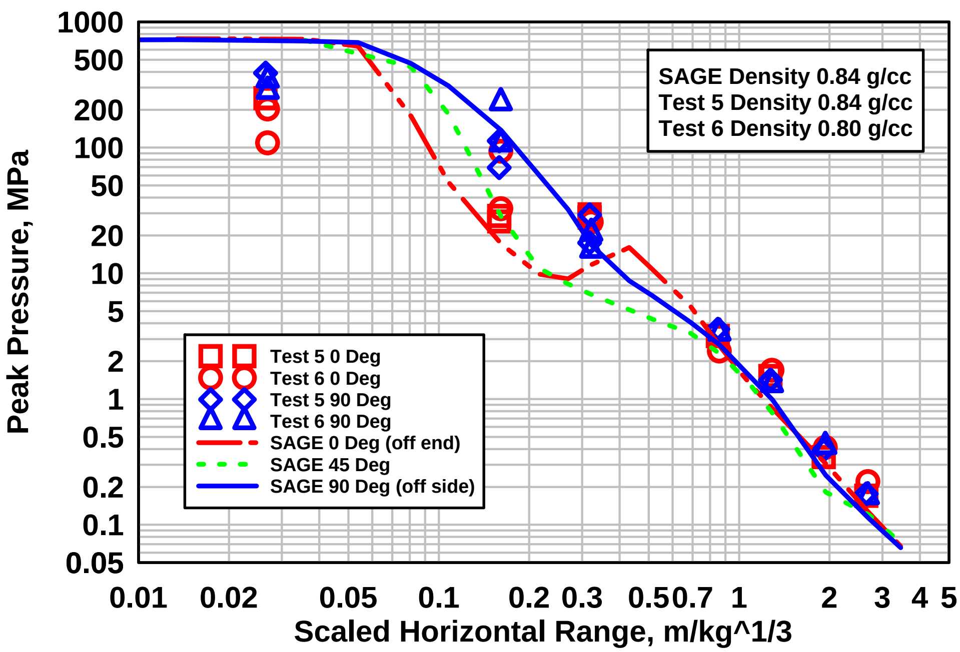

Figure 7. Comparison of measured and calculated peak pressures for Tests 5 and 6.

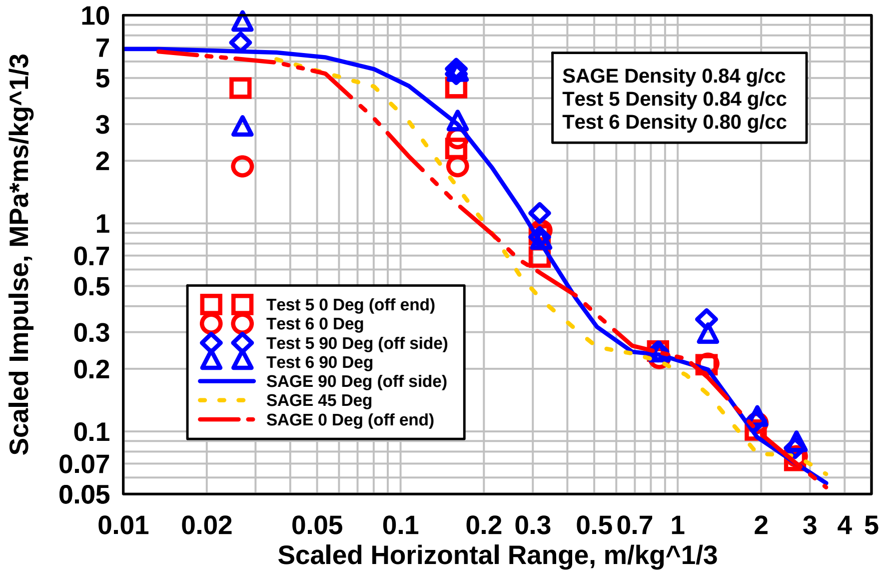

Figure 8. Comparison of measured and calculated impulses for Tests 5 and 6.

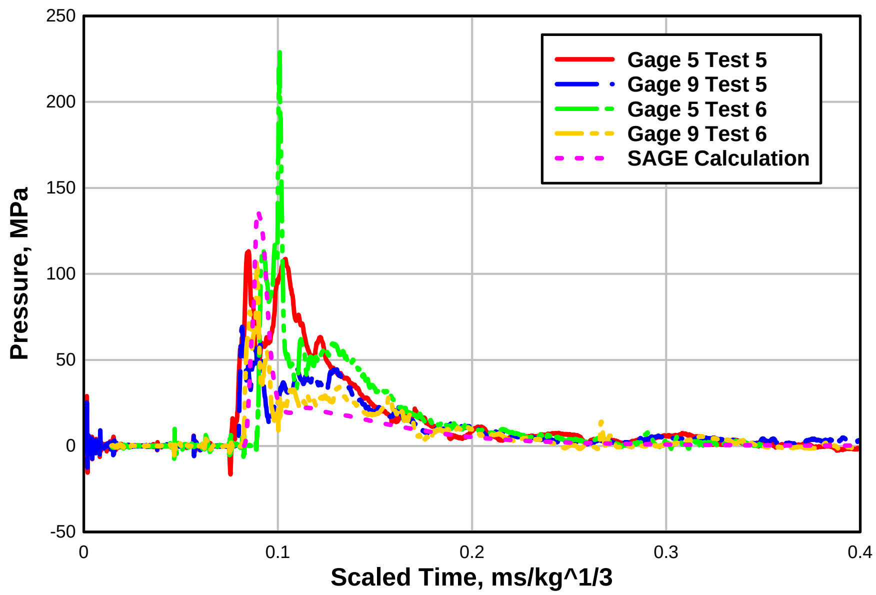

Figure 9. Comparison of measured and calculated pressure waveforms at the 0.161-m/kg$^{1/3}$ scaled range and on the 90-deg radial.

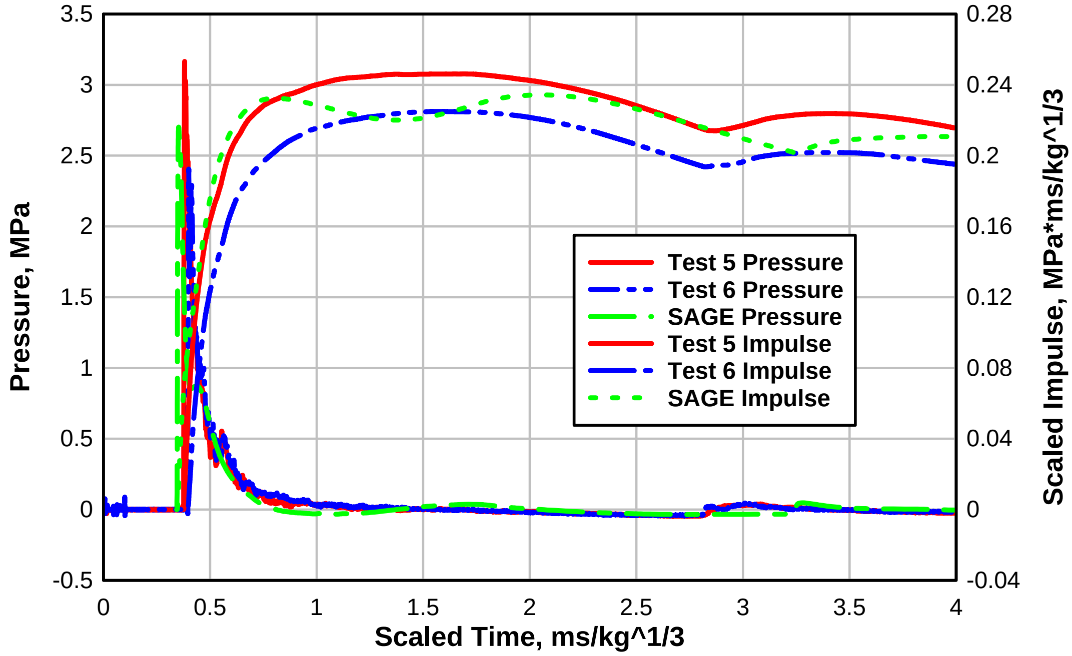

Figure 10. Measured and calculated pressure and impulse waveforms at the 0.858-m/kg$^{1/3}$ scaled range and on the 0-deg radial.

CLOSE-IN AIRBLAST (CAB) CODE

Results of our experimental program are being used to validate and improve the close-in reflection model of the engineering-level code CAB (Close-In Airblast). This code has an easy-to-use graphical user interface similar to the CONWEP code [11] and uses the explosive source and reflections models from a version of the dynamic link library (DLL) used by the BlastX code [12] version 7.0. Unlike CONWEP, CAB includes reflections from a ground plane and a vertical wall. A large selection of explosives is available that includes common military explosives such as TNT, many fertilizer-based compositions, and other oxidizer-fuel explosives. Spheres and several cylindrical charge shapes of various L/D ratios are also included.

Figures 11 and 12 show input screens of CAB for a cylindrical charge of Composition C-4 that may be oriented in any direction by using drag and drop or input of coordinates. Three different views are available of the charge orientation and location relative to the reflecting planes. Output includes peak pressure and impulse at a point or a distribution on a wall, as in Figure 13. Pressure waveforms are also available. Metric or U. S. customary units may be used.

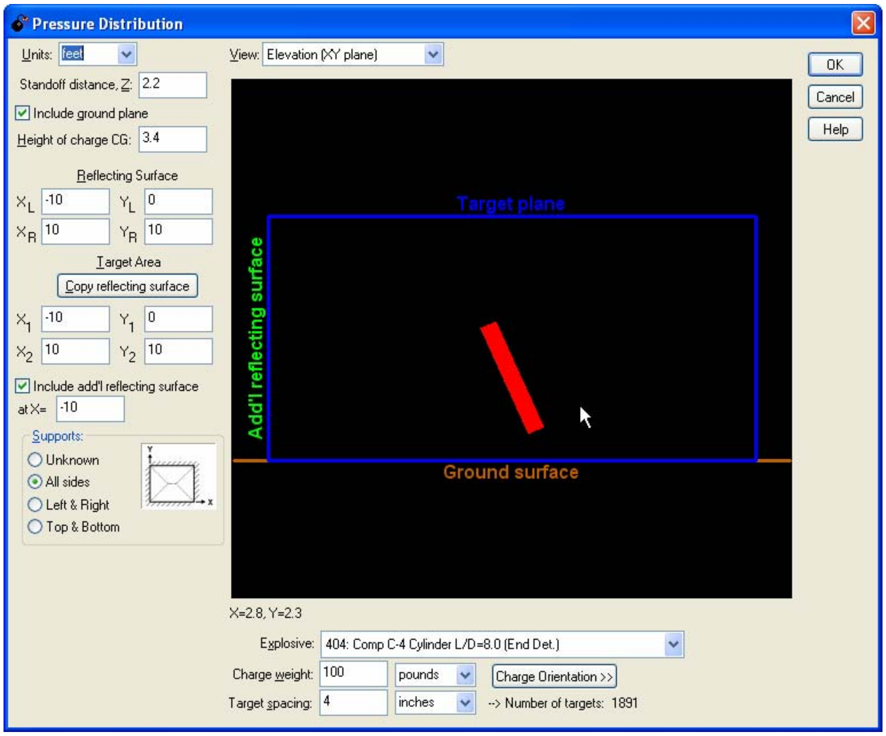

Figure 11. Data entry screen for the CAB code showing a cylindrical charge.

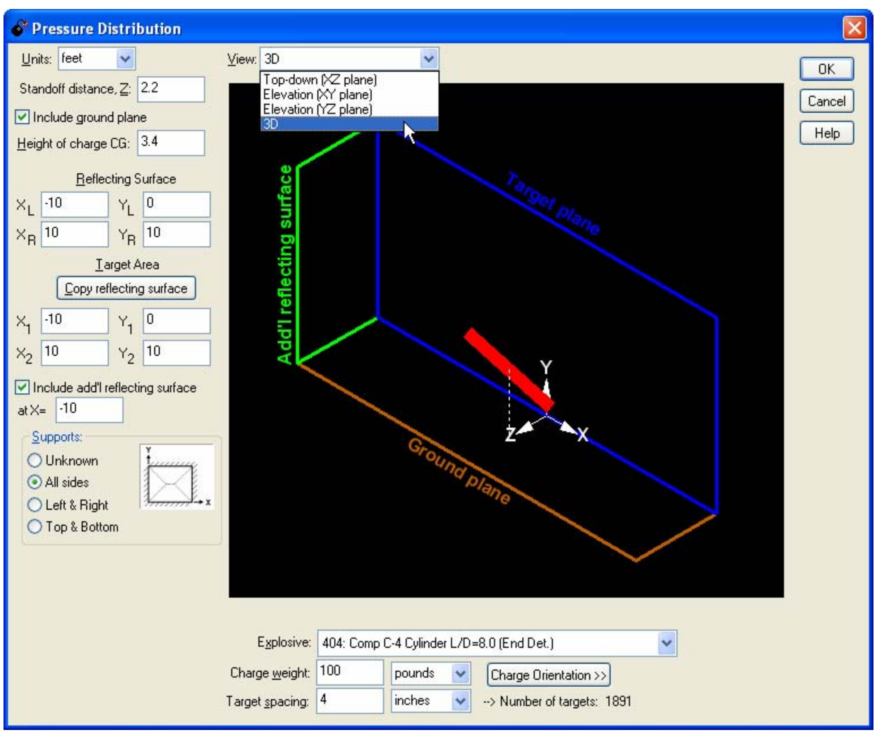

Figure 12. Multiple views for target plane and charge orientation.

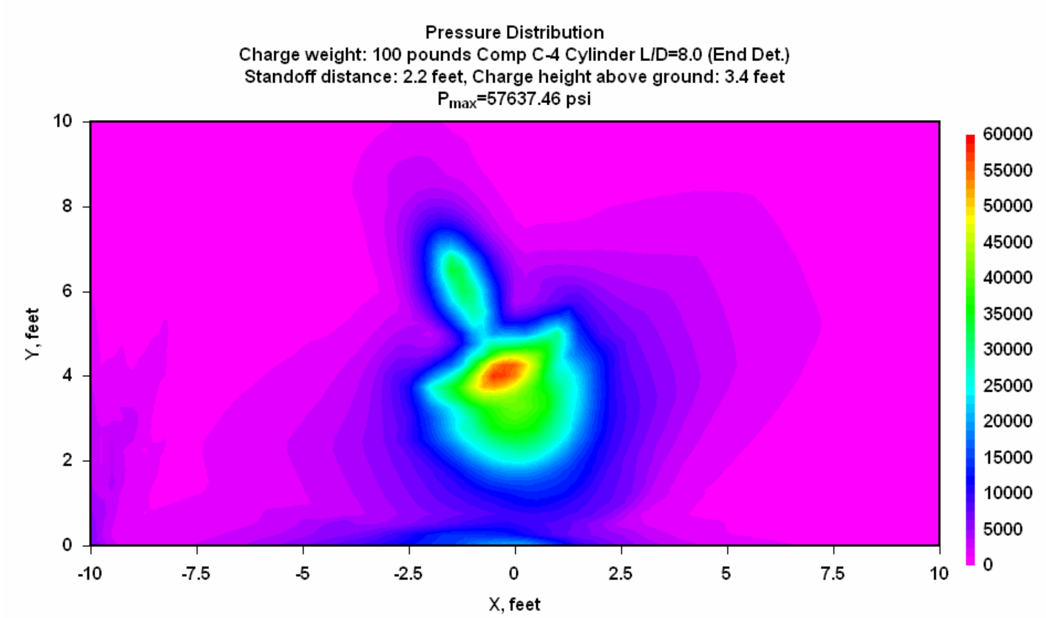

Figure 13. Peak pressure distribution on a wall computed by CAB.

SUMMARY AND CONCLUSIONS

The first phase of our experimental field test program provided airblast measurements in the close-in (above about 250 MPa) region for several standoff distances using cylindrical and box-shaped charges of ANFO. In the second phase, additional explosive compositions commonly used in makeshift devices were investigated. We also obtained pressure measurements at larger distances that may be compared with previous measurements by EMRTC and other organizations.

Our measurements provided information for modeling close-in airblast from a highly non-ideal explosive using high-fidelity, computational fluid dynamics codes, as well as developmental engineering-level codes such as CAB. Our results indicate calculations of close-in blast require accurate models of explosive detonation specifically for the size and composition of explosive charges being used. We had some success in applying IG detonation models that will predict blast from ANFO in charge weights from 10s of kg to 100,000s of kg. However, additional model refinement in the close-in region is needed.

REFERENCES

[1] Gittings, M., et al. (15 authors), 2005, "SAGE Users Manual," LA-UR-04-2959 Rev. 3, Los Alamos National Laboratory.
[2] Lee, E. L., Hornig, H. C. and Kury, J. W., 1968, "Adiabatic Expansion of High Explosive Detonation Products," UCRL-50422, Lawrence Livermore National Laboratory.

[3] Fried, L. E., Howard, W. M. and Souers, P. C., 2005, “Cheetah 4.0 User’s Manual,” Energetic Materials Center, Lawrence Livermore National Laboratory. See also “Cheetah 2.0 User’s Manual,” UCRL-MA-117541 Rev. 5, 1998.
[4] Petes, J., Miller, R., and McMullan, F., 1983, “User’s Guide and History of ANFO as a Nuclear Weapons Effect Simulation Explosive,” DNA-TR-82-156, Defense Nuclear Agency.
[5] Helm, F., Finger, M., Hayes, B., Lee, E., Cheung, H, and Walton, J., 1976, “High Explosive Characterization for the DICE THROW Event,” UCRL-52042, Lawrence Livermore National Laboratory.
[6] Lee, E. L. and C. M. Tarver, 1980, “Phenomenological Model of Shock Initiation in Heterogeneous Explosives,” Phys. Fluids, Vol. 23, No. 12.
[7] Lattery, J., Sandstrom, F. W., and Leone, M. G., 2000, “TNT Equivalency of Small-Scale Hemispherical Surface Bursts of Ideal and Non-Ideal Explosives,” Twenty-Ninth Department of Defense Explosive Safety Seminar.
[8] Mulford, R. N., Swift, D. C., Braithwaite, M., 2002, “Temperature-Based Reactive Flow Model for ANFO,” Proceedings of the 12th Detonation Symposium.
[9] Bdzil, J. B., Aslam, T. D., Catanach, R. A., Hill, L. G., Short, M., 2002, “DSD Front Models: Nonideal Explosive Detonation in ANFO,” Proceedings of the 12th Detonation Symposium.
[10] Braithwaite, M., Cunningham, C. V., Sharpe, G. J., 2006, “Modeling and Numerical Simulation of Steady Detonations in Highly Non-Ideal Explosives,” Proceedings of the 13th Detonation Symposium.
[11] Hyde, D. W., CONWEP Code, distributed by U. S. Army Engineer Research and Development Center, Vicksburg, MS.
[12] Britt, J. R., Ranta, D. E., and Joachim, C. E., “BlastX Code, Version 4.2 User’s Manual,” 2001, ERDC/GSL TR-01-2, USACE Engineer Research and Development Center, Vicksburg, MS.